International Journal of Computer Science and Engineering (IJCSE)
ISSN(P): 2278-9960; ISSN(E): 2278-9979
Vol. 3, Issue 1, Jan 2014, 29-38

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

DAMAGE DETECTION USING A NON-DESTRUCTIVE TECHNIQUE FOR INSPECTION WIND TURBINE BLADES

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ABSTRACT

The increasing of the use renewable power sources in the next decades which make the use of non-destructive testing techniques will improve the regular inspections of wind turbine blades. There are several techniques for non destructive testing such as thermography, x-ray imaging, acoustic emission vibration analysis and ultrasonic testing. In this paper we evaluated the measurements of the propagation characteristics of waves that are used to determine material properties; this technique is useful for detection of flaws to discover damages at the boundary surfaces. The ultrasonic A- scan and C-scan imaging are used for the area to map interface disband. This method of testing object be carefully planned with regard to safety economic and high efficiency and investigated during the pulse–echo technique developed for practical applications.

KEYWORDS: Ultrasonic, Echo, Technique, Wind Turbine Blade, NDT Techniques, A-Scan, C-Scan

INTRODUCTION

Ultrasonic (NDE) non-destructive Evaluation is one of the most widely methods today to examine an object, material or system as a way of finding out the nature of a solid material-its thickness, its flaw, its elasticity and more this knowledge has many applications in aircraft, piping, semiconductor fabrication, railroad and other industries [1]. An ultrasonic NDT has been used to test wind turbine blades. This technique is based on ultrasonic waves which might have higher frequency more than 20khz. are generated and propagate into a material by a transducer to transmit and receive the reflecting signal at the same time to test the material's composition, structure, elastic properties, density and

The blades are important components in wind turbines, so they are needed to be investigated and supervised regularly. The sample which has been inspected for the sake consists of two layers; the top gel-coat layer (varies in thickness between 1mm and 3mm), the bottom layer is glass-reinforced plastic (GRP) which has a constant thickness of 4mm.

In this paper, ultrasonic NDT techniques, suitable for testing of wind turbine blade is used for inspection flaws between the GFRP layers appear like delamination or lake which is the most technology applied for condition monitoring.

Ultrasound – Echo Technique

In principle, the pulse technique is the simplest of all the ultrasonic testing methods, and it is the one most commonly used, it consists basically of measuring the time taken for short train of sound waves to move through a given distance [3].

This distance can determine if the speed of sound in the material is known, or if the distance be known, then seeped of sound can rapidly calculate by measuring the relative amplitude of pulses which have travelled different distance, which can determine the attenuation coefficient. The principle is shown in Figure 1 is very simple. An ultrasonic pulse is sent into the test specimen using an ultrasonic transducer.

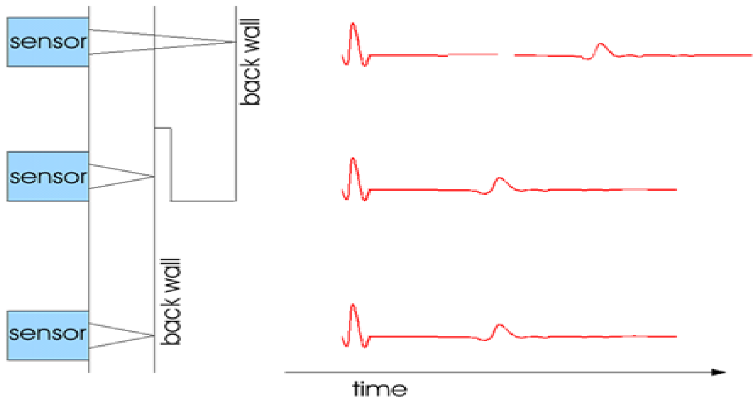

Figure 1: Principle of an Ultrasound-Echo Measurement

The waves are traveling through the specimen and are reflected at the back wall or at flaws within the material. The reflected waves are recorded using the same transducer. A longer travel path results in a later echo [2].

The location of the back wall echo therefore gives information about the thickness of the inspected structure. This technique will be used to detect areas of missing bond between the belt and the bars within the wind turbine blades.

The ultrasonic waves have to travel through several centimeters of GFRP, which is due to the fibers a highly sound scattering and damping material. Therefore a high voltage ultrasonic pulse is used to send enough energy into the material. The wind turbine is fast growing and very source of environmentally safe and renewable energy with a high potential. It is necessary to perform continuous condition monitoring of wind turbine blades in order to estimate the level of a critical damage as the initial stage before collapsing its. The wind turbine blade can split into three main regions. Each region has a different multilayered structure, however, in each case the main defects are disbanded and delamination and porosity [3 & 4].

The turbine blades consist of glass fiber reinforced plastics (GFRP), gelcoat and sandwich areas containing plastic foam covered with layer GRP [3]. Nowadays it is common to use non-contact ultrasonic through transmission techniques like air-coupled ultrasound to detect the inner damages [5].

The Reflection Coefficient

The reflection coefficient can be defined as a ratio between the magnitude of the incident wave propagation towards the discontinuity and the reflected wave travelling in an opposite direction. Firstly, to obtain this we need to calculate the acoustic impedance of material by law [2].

The characteristic impedance is defined as:

$$Z = \rho . c \tag{1}$$

Where, Z is the characteristic acoustic impedance

ρ is the density of the medium

c is the compression\shear wave speed

Then is easy to calculate for every material by using this property and the reflection coefficient is evaluated in the equation below between two different mediums.

$$Γ = (Z2-Z1)/ (Z2+Z1) \tag{2}$$

From the equation above the magnitude of this reflected waves depends upon how different the values of Z2, Z1 are the more different they are higher the percentage of the wave's energy is reflected back. The sample consists of two layers; the top gel coat layer may vary in thickness between 1 mm and 3mm. The second layer is glass reinforced plastic GRP and is 4 mm in thickness throughout. In NDT testing it is necessary to measure gelcaot slab, the far boundary will be between the gelcaot and the surrounding air.

Gelcoat: Compression velocity: 2608.00 m\s

Density: 1100.00 kg\m*3

Z shoe: Compression velocity: 2324.00 m\s

Density: 1077.00 kg\m*3

Now to calculate the characteristic acoustic impedance using:

Z =ρ.c

Zgel= 2608*1100 =2.868*10^6

zshoe=2324*1077 =2.502*10*6

Ґ= (2868800 - 2502948) / (2868800 + 2502948) = 0.146.

The magnitude of the reflection coefficient is 0.146 the reflected wave has a smaller amplitude. Moving to a wave which is transmitted into the further medium at the boundary between GRP and the top gelcoat, some of the wave`s power reflects back the way it came and some propagated through the boundary. It follows that mathematicians about the second layer GRP could be situated adjacent to gelcoat layer. Again to find the reflection coefficient between them the velocity and the density of the material GRP is shown below:

Compression Velocity: 2603.00 m\s

Density: 3500 kg\m*

Now to calculate the characteristic acoustic impedance using:

Z =ρ.c

ZGRP=26O3*3500= 9.110*10^6

Zgel = 2608*1100 = s 2.868*10^6

Ґ=(9.110-2.868)\(9.110+2.868) = 0.52

The transmission will be:T=1- Ґ= 1-0.52=0.48

From this calculation we can notice that at this boundary between gelcaot and GRP 52% of the wave power is reflected and 48% of the wave is transmitted.

The Propagation of Ultrasonic Waves

In solids, sound waves can propagate in four principle modes that are based on the way the particles oscillate. Sound can propagate as longitudinal waves, shear waves, surface waves, and in thin materials as plate waves. However, Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. The particle movement responsible for the propagation of longitudinal and shear wave is illustrated as shown in figure 2 below.

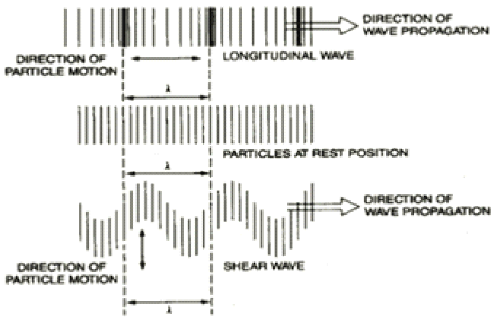

Figure 2: Graphical Representation of the Generation of Compression and Shear Waves

In Longitudinal or compression waves the movement of the particle is in the same direction as the wave propagates this because as the particle a compress against its neighbor energy is transferred from particle to particle and this continues along the wave.

In Shear or transverse waves the particle movement is perpendicular to the wave'sPropagation, this type of waves is only present in acoustically solid material and does not propagate through liquid or gases. However during this project all waves propagate into the sample at an angle of incidence 90 degrees. This means only one type of wave can generate by the transducer at any one time. Also, after simulation the data need to be presented and interpreted to give information into the nature of the sample. This is achieved by three ways, called A-scans, B-scan and C-scans. However, the particular scanning technique is used in this project A & C Scans.

A- Scan

The A-scan plots received signal amplitude against time, with energy plotted on the Y-axis of the data produced by single ultrasound measurement at a single point; the amplitude of a peak indicates the amount of energy received by the boundary and the higher reflection coefficient the more energy that is received back by the transducer. The location of the peak in the X-direction gives the user information into the depth of the defect; as the nearer peaks are closer the transducer. The location of defect is using time of flight. Calculation can be made about layer thickness.

The voltage represented sound amplitude against time for all various echoes which have different propagation paths through the test object depended on the reflection and transmission coefficient of each layer. Also, it is possible defect defects by data analysis or comparison with ideal data. However, an A-scan gives information at one point only.

Defect Types

There are different types of defects can observe from ultrasound pulse –echo techniques when are sensitive to them and see its location within the sample.

Disbond \ Delamination (Front\Back Face)

This is defined as an air gap between two materials which are caused during the production or applied stress inducing a disbond. They occur in any material that has several layers and will have an effect on the integrity and strength of the material.

Denominations are becoming more important to detect. This failure can be caused by a number of reasons; material fatigue, impact, repeated temperature changes etc.

Front face refers to the air gap on the tester's side of the boundary and back face refers to delamination on the further side of the boundary [1, 2].

Porosity

This is a series of very small bubbles throughout the material which will cause energy to be lost in the propagation ultrasonic wave. This may occur due to incorrect solidification of the adhesive. The energy loss is due to the sound wave being scattered by the bubble [6].

Data Measurement and the Result

These tests have yielded important insights into technique for experimental damage detection on real structures from using simulation package and material property. The method of interpretation set out in this section is very useful to identify peaks from ultrasonic tests. In this paper analysis each defect type by calculating each individual path through the sample. The basis of ultrasonic testing is to convert electrical energy into acoustic and vice versa by using a transducer generally have a center frequency depend on the methods or structure being used; lower frequencies have longer time duration pulses so are not suitable for testing thin layers.

Pulse-echo results from a transducer10 MHZ and shoe in contact with a sample, the main challenges when interpretation their A-scan is matching the A-scan echoes with its corresponding propagation path through testing sample. The diagram below shows 4 potential echo paths through a 2- layered for a sample section of gelcoat and GRP (glass-reinforced plastic): the top gelcoat layer may vary in thickness between 1mm and 3mm. the second layer is GRP and 4mm.

The first echo (1) is a pulse reflected from the buffer\shoe and the top of the gelcoat, the second echo is the pulse between the gelcoat and the GRP. Echo (3) is the second reverberation in gelcoat. Echo (4) back face echo. By calculating the time each echo takes to return to transducer, and the values for compression wave speed as below:

Gelcoat 2608

GRP 2603

A simple calculation can be performed to find thickness as below:

$$\text{Thickness} = 0.5(\Delta T * \text{Speed}) \quad (3)$$

The expected values are shown within the table below depended on the variable values of Δt gel &ΔtGRP to find the thickness of gel coat and GRP.

Table 1: Thickness Gel Coat and GRB

Type	Δt gel	Thicker Gel mm	Δt GRP	Thickness GRPmm
Type 1	0.00000122-0.00000046	1.004	4.20*10^-6-0.00000121	3.891 (4mm)
Type 2	0.00000123-0.00000046	1.017	1.99*10^-6-0.00000123	0.989 (1mm)
Type 3	1.99*10^-6-0.00000045	2.008	4.98*10^-6-1.98*10^-6	3.904 (4mm)
Type 4	1.22*10^-6-4.5*10^-7	1.004	3.49*10^-6-1.21*10^-6	2.967 (3mm)
Type 5	1.94*10^-6-0.00000045	1.916		-----------
Type 6	0.00000155-0.00000045	0.938		------------
Type 7	0.00000118-0.00000046	1.434		-------------

By plotting the pulse-echo data which is supplied by the client, 36 A-scans but only seven different A-scan types are explained.

The First Type: It includes six A-scans (A1, A5, B1, D1, D2 and E2) and each is plotted as in figure 3, the first echo represents the top surface of the gel-cot and clearly has a low amplitude because of the similarities between the shoe

and the gel-coat (the both acoustic impedances are approximately similar as explained before, the waves transmit because the reflection coefficient is (0.146).

The second echo, the back surface of the gel-coat and it has obviously a relatively high amplitude due to the fact that the GRP existence in the second layer and the different properties between the gel-coat and the GRP, so the reflection coefficient is (0.52).

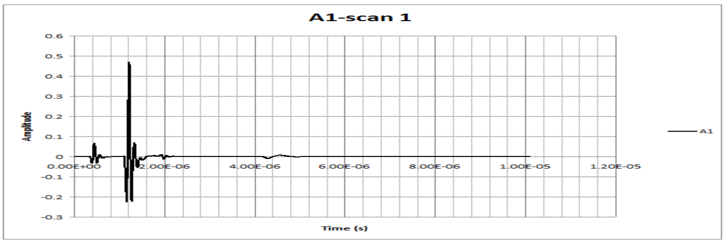

Figure 3: The First Type Plot of A-Scan

From the material (transducer shoe, gel-coat and GRP) property data which is also provided by the client and is plotted in figure 4, 5 and 6 respectively, the density and wave velocity in all three materials can be obtained with no much change in the wave velocity corresponding to the frequency. Consequently, velocities of 2324 m/s, 2608m/s and 2603m/s in the shoe, gel-coat and GRP are chosen.

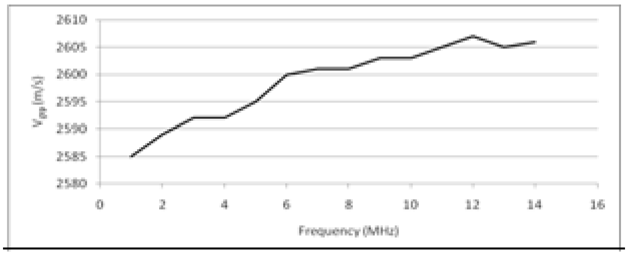

Figure 4: Wave Velocity in Transducer Shoe with Respect to Frequency

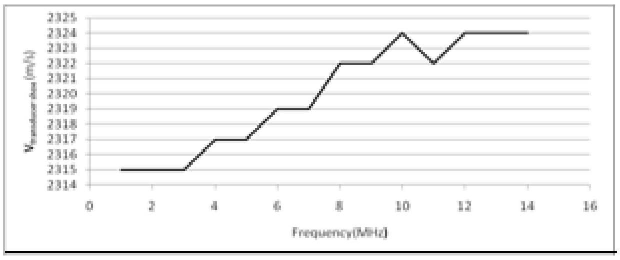

Figure 5: Wave Velocity in Gel-Coat with Respect to Frequency

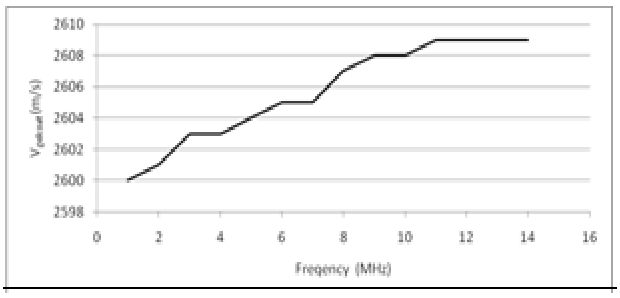

Figure 6: Wave Velocity in GRP with Respect to Frequency

From the first and the second echoes, which come from the top and the back surface of the gel-coat, the thickness of the gel-coat from the table above:Where, t1 is the time when the first echo arrive and t2 is the time when second echo arrives,

Therefore, d1 ≈ 1 mm(thickness gel coat)

Echo (2), which is existed, as mentioned before, due to gel coat to the GRP, is not inverted, no disbond is discovered. Moreover, the existence of a disbond makes the echo invert because the acoustic impedance of the air is much lower than the gel-coat. To interpret the third and the forth echoes well, the time of the expected backface echo from the GRP should be calculated and this can be done by using equation (3):

dgrp=0.5 (vgrp* tbf) (4)

Where, t bf is the time in which the wave travels through the GRP and comes back .

Therefore,

t bf = (2*dgrp)\ vgrp (5)

The time when the expected backface echo arrives = t2 + t bf (6)

This is the same time of the forth echo in the plot in figure 3 which means that this echo is the back face echo from the GRP and the smaller shape is due to the attenuation in the GRP, as shown figure 7.

Echo (3), the second reverberation in gel coat. Furthermore, echo (4) occurs therefor energy goes into GRP.

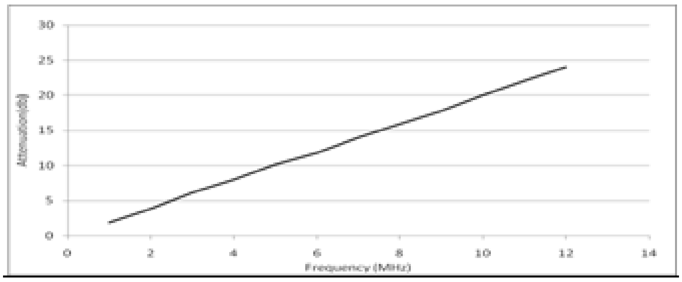

Figure 7: Attenuation in GRP with Respect to Frequency

The Second Type: This type contains five identical A-scans (A2,A3,A4,B2 and B3), figure 8 shows the plot.

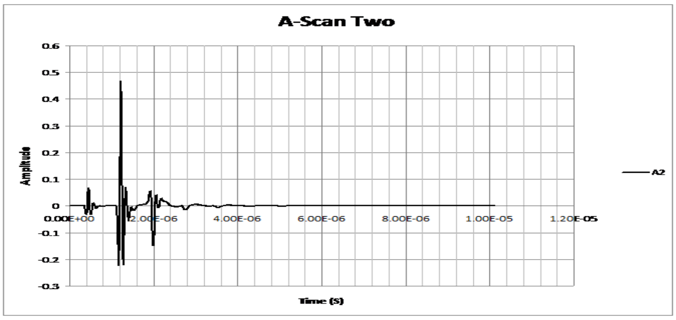

Figure 8: The Second Type Plot of A-Scan

The second type plot indicates that the first two echoes are almost the same as the previous type echoes. Consequently, the gel-coat thickness is:

d2 = 2608x (12.3x10^{-7} -4.6x10^{-7}) / 2 =1.017 mm

The third echo has an amplitude compared to the one in the first type (which is taken as a reference as no defect is existed), so it could not be a reverberation to the gel-coat. Furthermore, the fourth and fifth echoes do not appear in the first type. As a result, the last two echoes have to come from the GRP layer and as they are equally spaced, this shows that they might be multiple reverberations in the GRP.

In addition, the explanation for the large echo is due to the constructive interference in the GRP which means two or more echoes arrive at the same time and the back face echo for the GRP could be one of them [2,7].

The Third Type: This type includes nine A-scans (A6, B5, 6, C4-6, D4, 5, and E3,5), each one is plotted as in figure 9.

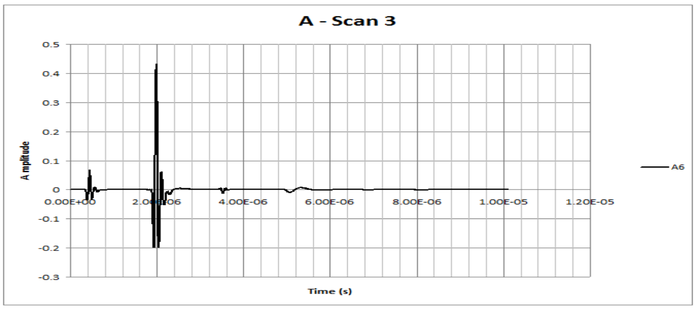

Figure 9: The Third Type Plot of A-Scan

The echoes in this type are similar to the ones in the first type except the fourth echoing, the thickness of the gel-coat (d_3) =2mm and the time of the expected backface echo from the GRP (t_{bf}) = $49.8x10^{-7}$ s.

If blackface is much lower amplitude by comparing with a-perfect sample it is easily noticeable that a small peak is visible because of the nature of porosity that is defined as a series of very small air bubbles throughout the material which will cause energy to be lost by the propagation ultrasonic wave. The scattered waves appear as random noise imposed on the front and back so that the amount of wave energy that is scattered depends on the size of the scattering particles compared to the wavelength of the ultrasonic wave. However, porosity is not determined during this inspection.

The Fourth Type: This type includes five A-scans (B4,C1-3,D3) each one is plotted as in figure 10.

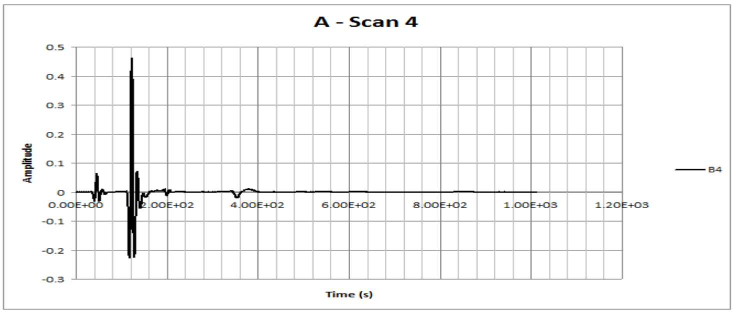

Figure 10: The Fourth Type Plot of A-Scan

The echoes in this type are similar to the first type except the fourth echo.

As the thickness of the gel-coat (d_4) =1mm and the time of the expected backface echo from the GRP (t_{bf}) = $34.9x10^{-7}$s. However, there is no echo occurring at this time while the fourth echo arrives before this time and exactly in the second of 12.1x10-7 which indicates that a defect (delamination) is discovered. The depth of the delamination is determined by applying equation (3).

And from the table of thickness above:Therefore, the depth of delamination $=2603x22.8x10^{-7} / 2 \approx 3$

This is mean that the delamination is at 3 mm from the front surface of the GRP and at 4 mm (1mm + 3mm) from the surface of the gelcoat.

The Fifth Type: In this type five A-scans (D6.E6,F4-6), each is plotted as shown in figure 11.

Thickness of the gel-coat is also obtained from the table above:

d_5= 2608x (12.3x10^{-7} - 4.5x10^{-7}) / 2 = 1.916 mm.However, the inversion of the second echo besides the high amplitude which all indicate that a disbond is existed between the gel-coat and the GRP.

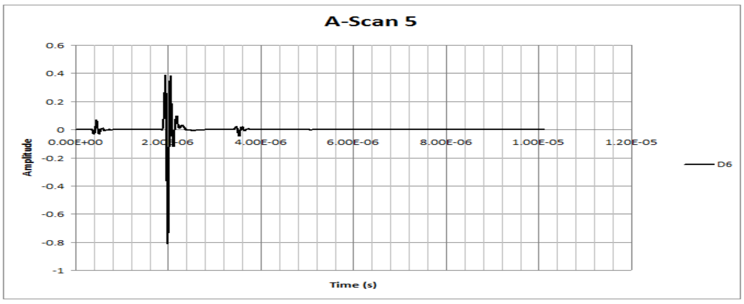

Figure 11: The Fifth Type Plot of A-Scan

C-Scan

C-scan is just the product of several A-scan over a large area whereas, A- scan only describe the sample at one particular point. C-scans give a very nice a comprehensive three dimensional picture of the entire sampling, easy to analysis the shape of the defect to the operator by color map of part of a structure.

A-scan e.g. arrival time of the particular peak which would give layer thickness at the point or maybe the amplitude of a particular peak, which might give an indication of attenuation to form a C-scan a series of A scan measurements for example using the pulse echo technique across the surface area of the test object. This is done in a logical grid formation. So for each measurement position there will be an A- scan.

As shown in figure 12, the layer thickness can put into grid representing the test object. It is normal then to color code this information in the form of color contour map. Here we can see the thickness of a delicate layer change from thin in lower left hand corner test object to thicker in the right hand corner [7].

	A	B	C	D	E	F
1	1.004	1.004	1.004	1.004	0.938	0.938
2	1.017	1.017	1.004	1.004	1.004	0.938
3	1.017	1.017	1.004	1.004	2.008	1.434
4	1.017	1.004	2.008	2.008	1.434	1.916
5	1.004	2.008	2.008	2.008	2.008	1.916
6	2.008	2.008	2.008	1.916	1.916	1.916

Figure 12: C-Scan Format

Another type of C-scan as is shown in figure 13 to detect disbonds and delaminations. It is the amplitude data will be most useful generally, the pulse will be transmitted into the top substrate layer and some energy will then be transmitted into the second layer. However, a disbond is where a gap between them this is usually a very thin air gap no energy into GRP. Red disdond, green OK and thickness of grp is less 4mm equal delamination (yellow) [7].

	A	B	C	D	E	F
1			3mm			
2	1mm	1mm	3mm			
3	1mm	1mm	3mm	3mm		
4	1mm	3mm				
5						
6						

Figure 13: C-Scan Disbond(Red) & Delamination(Yellow)

CONCLUSIONS

Pulse –echo measurement technique of measurements the ultrasonic waves by using the PROMAT and the characteristic of these graphs to identify defects in sample of wind turbine blade structures. It was possible to investigate the propagation characteristic of all the different defects set out in theory and the method of interpretation which is useful to identify the defects including disbonds and delaminations which were presented and indicated. IN the future, it would possible to generate this technique allowing quicker analysis of each A-scan. That any person wishing to understand industrial ultrasonic waves. This technique for the inspection of wind turbine blade has the advantages to work during the tests. However, the influence of overlapped reflections, scattering and attenuation of the reflected ultrasonic waves from multi-layered structure takes place. This effect has a negative impact on the propagation of ultrasonic waves.

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